APPLICATION UNDER UNITED STATES PATENT LAWS

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Invention: LITHOGRAPHIC PROJECTION APPARATUS, DEVICE MANUFACTURING METHOD, DEVICE MANUFACTURED THEREBY

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SPECIFICATION

Lithographic Projection Apparatus, Device Manufacturing Method and Device Manufactured Thereby

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates generally to lithographic projection apparatus and more particularly to lithographic projection apparatus including a purge gas system.

2. Background of the Related Art

[0002] A typical lithographic apparatus as described herein includes a radiation system for supplying a projection beam of electromagnetic radiation having a wavelength of 250nm or less, a support structure for supporting patterning structure, the patterning structure serving to pattern the projection beam according to a desired pattern, a substrate table for holding a substrate, and a projection system for projecting the patterned beam onto a target portion of the substrate.

[0003] The term "patterning structure" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning structure include:

[0004] A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the

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mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.

[0005] A programmable mirror array. An example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from US 5,296,891 and US 5,523,193, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0006] A programmable LCD array. An example of such a construction is given in US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0007] For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning structure as hereabove set forth.

[0008] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning structure may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (*e.g.* comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion at once; such an apparatus is commonly referred to as a wafer

stepper. In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

[0009] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0010] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a “lens”. Further, the lithographic apparatus may be of a type having two or more substrate tables

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(and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Twin stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, both incorporated herein by reference.

[0011] To reduce the size of features that can be imaged using a lithographic projection apparatus, it is desirable to reduce the wavelength of the illumination radiation. Ultraviolet wavelengths of less than 200nm are therefore currently contemplated, for example 193nm, 157nm or 126nm. Also contemplated are extreme ultraviolet (EUV) wavelengths of less than 50nm, for example 13.5nm. Suitable sources of UV radiation include Hg lamps and excimer lasers. EUV sources contemplated include laser-produced plasma sources, discharge sources and undulators or wigglers provided around the path of an electron beam in a storage ring or synchrotron.

[0012] In the case of EUV radiation, the projection system will generally consist of an array of mirrors, and the mask will be reflective; see, for example, the apparatus discussed in WO 99/57596, incorporated herein by reference.

[0013] Apparatus which operate at such low wavelengths are significantly more sensitive to the presence of contaminant particles than those operating at higher wavelengths. Contaminant particles such as hydrocarbon molecules and water vapor may be introduced into the system from external sources, or they may be generated within the lithographic apparatus itself. For example the contaminant particles may include the debris and by-products that are liberated from the substrate, for example by an EUV radiation beam, or molecules produced through evaporation of plastics, adhesives and lubricants used in the apparatus.

[0014] These contaminants tend to adsorb to optical components in the system, and cause a loss in transmission of the radiation beam. When using, for example, 157nm radiation, a loss in transmission of about 1% is observed when only one or a few monolayers of contaminant particles form on each optical surface. Such a loss in transmission is unacceptably high. Further, the uniformity requirement on the projection beam intensity for such systems is generally less than 0.2%. Localized contamination on optical components can cause this requirement not to be met.

[0015] Previous methods for cleaning optical components include, for example, the use of ozone as a cleaning material. However, ozone is a very unstable material and degrades

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only a few hours after its formation. If ozone is to be used to clean the optical surfaces, it is therefore necessary to produce it either *in situ*, or immediately before cleaning. An ozonizer may, for example, be used for this purpose. However, the extra step of producing the ozone itself is highly inconvenient and an alternative cleaning method is desired which relies on more stable cleaning materials.

[0016] The use of more stable molecular oxygen in combination with UV radiation for cleaning purposes was contemplated by Bloomstein *et al.* (T.M. Bloomstein, M. Rothschild, V. Liberman, D. Hardy, N.N. Efremov Jr. and S.T. Palmacci, SPIE (Optical Microlithography XIII, Ed. C.J. Progler), Vol. 4000 (2000), 1537-1545). According to Bloomstein *et al.* practical levels of oxygen are restricted to the range of 10 to 1000 ppm due to absorption of 157 nm radiation.

SUMMARY OF THE INVENTION

[0017] One aspect of the invention includes providing a lithographic projection apparatus with an efficient and improved cleaning of one or more optical components.

[0018] This and other aspects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, wherein the apparatus further comprises a gas supply for supplying a purge gas to a space in said apparatus, said space containing an optical component positioned to interact with the projection beam, and wherein said purge gas comprises molecular oxygen at a partial pressure of from 1×10^{-4} Pa to 1 Pa.

[0019] The inventors have found that the cleaning of optical components in a lithographic projection apparatus can be carried out by addition of relatively low partial pressures of stable molecular oxygen to a purge gas which is fed to spaces through which the projection beam travels. As molecular oxygen itself is not effective as cleaning agent, it is used in combination with UV radiation. The UV radiation cracks oxygen to produce oxygen radicals, which are highly effective cleaning agents. With the said low concentrations of cleaning agent in the purge gas, the optical components can be cleaned while projecting a mask pattern onto a target portion with acceptable transmission loss due to absorption of UV radiation by oxygen.

[0020] After cleaning according to the invention, the transmission or reflection of the radiation beam is increased and the uniformity may also be improved. The invention therefore

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provides a highly effective method of cleaning optical components in lithographic projection apparatus. It avoids the use of unstable materials such as ozone. Above all, it prevents very time-consuming dismounting of optical components (e.g. lens elements) out of the lithographic projection apparatus in order to clean the component in a separate cleaning unit.

[0021] According to a further aspect of the present invention there is provided a device manufacturing method comprising providing a substrate that is at least partially covered by a layer of radiation-sensitive material providing a projection beam of electromagnetic radiation having a wavelength of 250nm or less using patterning structure to endow the projection beam with a pattern in its cross-section projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material, and cleaning an optical component for use in the apparatus by irradiating a space containing said optical component which is positioned to interact with the projection beam with the said projection beam and supplying to said space a purge gas comprising molecular oxygen at a total partial pressure of from 1×10^{-4} Pa to 1 Pa.

[0022] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0023] In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV or XUV) radiation (*e.g.* having a wavelength in the range 5-20 nm such as 12.5 nm) or soft x-rays, as well as particle beams, such as ion beams or electron beams.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The invention and its attendant advantages will be further described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

[0025] Figure 1 depicts a lithographic projection apparatus according to the invention;

[0026] Figure 2 depicts a part of the illumination system of an embodiment of the invention; and

[0027] Figure 3 depicts a part of the illumination system of a further embodiment of the invention.

[0028] In the drawings, like parts are identified by like references.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0029] Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

[0030] a radiation system LA, IL for supplying a projection beam PB of UV or EUV radiation;

[0031] a first object table (mask table) MT for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

[0032] a second object table (substrate or wafer table) WT for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;

[0033] a projection system ("lens") PL (e.g. a mirror group) for imaging an irradiated portion of the mask MA onto an exposure area C of a substrate W held on the substrate table WT.

[0034] As here depicted, the apparatus is of a reflective type (i.e. has a reflective mask). However, in general, it may also be of a transmissive type, for example.

[0035] The radiation system may include a source LA (e.g. an Hg lamp, an excimer laser, a laser-produced plasma source, a discharge plasma source or an undulator or wiggler provided around the path of an electron beam in a storage ring or synchrotron) which produces a beam of UV or EUV radiation. This beam is caused to traverse various optical components comprised in the illumination system IL – e.g. beam shaping optics, an integrator and a condenser – also included in the radiation system so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

[0036] The beam PB subsequently intercepts the mask MA which is held on a mask table MT. Having been selectively reflected by the mask MA, the beam PB traverses the lens PL, which focuses the beam PB onto an exposure area C of the substrate W. With the aid of the interferometric displacement measuring means IF, the substrate table WT can be moved accurately by the second positioning means, e.g. so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus) the mask table may be connected only to a short-stroke positioning device, to make fine adjustments in mask orientation and position, or it may simply be fixed.

[0037] The depicted apparatus can be used in two different modes:

[0038] In step-and-repeat (step) mode, the mask table MT is kept essentially stationary, and an entire mask image is projected at once (i.e. a single "flash") onto an exposure area C. The substrate table WT is then shifted in the X and/or Y directions so that a different exposure area C can be irradiated by the beam PB;

[0039] In step-and-scan (scan) mode, essentially the same scenario applies, except that a given exposure area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is moved in the same or opposite direction at a speed V = Mv, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large exposure area C can be exposed, without having to compromise on resolution.

[0040] In an embodiment of the present invention, the optical component to be cleaned is an optical component within the illumination system. However, the present invention may be used to remove contaminants from any optical component in the system, for example the mask or the optical components contained within the projection system. The present invention can be applied to one or several optical components either simultaneously or separately.

[0041] Figure 2 shows a part of the illumination system of a specific embodiment of the invention in more detail. A space 2 within the illumination system, and containing an

optical component 3, is supplied with a purge gas from purge gas supply 4, which may be a pressurized container containing the purge gas in gaseous or liquid form. The purge gas comprising molecular oxygen is supplied to the space 2 via inlet 5, which may comprise a valve. Space 2 now containing oxygen is then irradiated with UV or EUV radiation, which is produced by the source LA. In this embodiment, the irradiation step is carried out at the same time as exposure, i.e. the projection beam PB is used to crack oxygen.

[0042] Molecular oxygen within the space, when irradiated with UV or EUV radiation having a wavelength of about 250nm or less, are cracked, forming oxygen radicals. The oxygen radicals formed act as highly effective cleaning agents and remove hydrocarbons and other contaminant particles from the surface of the optical component.

[0043] In one embodiment of the present invention the space containing the optical component to be cleaned is purged with a substantially inert gas. In this case molecular oxygen is present in a small amount in the purge gas. The purge gas may comprise any gaseous composition which is suitable for use in a lithographic apparatus, together with oxygen. Typical purge gases comprise one or a mixture of inert gases such as noble gases or nitrogen, together with molecular oxygen. The inventors have found that particularly useful inert gases are argon, helium and nitrogen, for example ultra-pure nitrogen.

[0044] In particular embodiments of the present invention the purge gas compositions consist only of one or more inert gases and oxygen. In such embodiments, it may be advantageous to remove other contaminants from the gas. Typically, a purifier is used to remove hydrocarbons from the purge gas. It is possible to use a purifier in the present invention which removes most hydrocarbons but does not affect the presence of oxygen.

[0045] The total amount of molecular oxygen present in the purge gas is typically from about 1ppb to about 10ppm by volume. In an atmospheric environment, these amounts are equal to partial pressures of 1×10^{-4} Pa and 1 Pa, respectively. If the amount of oxygen is less than about 1 ppb by volume, the amount of contaminant which is removed from the optical component may be insufficient, unless cleaning is carried out for a period of several hours, which is in itself undesirable. Further, concentrations of below about 1 ppb are very difficult to detect.

[0046] Alternatively, if the concentration of oxygen is above about 10ppm by volume, the absorption of the projection beam by molecular oxygen is generally so high that the transmission is decreased below an acceptable level. The level of transmission loss due to this

absorption of the projection beam depends on the path length of the optical system to be cleaned. For example, the beam delivery system in general has a much longer path length than the illumination system and a decrease in transmission of 10% due to UV-absorption in the beam delivery system may equate to a decrease of around only 1% in the illumination system, given the same concentration of molecular oxygen. Therefore, while a concentration of around 1 ppm may be acceptable in an illumination system, systems with a longer path length may require lower concentrations such as 300 or 400 ppb.

[0047] In a variation of the first embodiment of the present invention, the space containing the optical component to be cleaned is evacuated. In this embodiment, the oxygen-containing species or mixture of oxygen is preferably substantially the only component(s) of the purge gas. The purge gas is introduced into the space at a low partial pressure. The pressure of molecular oxygen in the space must be sufficiently high that contaminants can be effectively cleaned from the optical component within a reasonable time, but sufficiently low that the transmission of the projection beam is not reduced below an acceptable level. Typically, the total partial pressure of oxygen present is from about $1x\ 10^{-4}$Pa to about 1 Pa. If the pressure is below about $1x10^{-4}$ Pa, cleaning must be carried out for several hours in order to remove a sufficient amount of contaminant. Conversely, if the pressure is above about 1 Pa, absorption of the (E)UV radiation by molecular oxygen is high, causing an unacceptable loss in transmission. As described above, the maximum acceptable amount of oxygen used may vary depending on the path length of the system to be cleaned.

[0048] If desired, the degree of contamination may be monitored using sensor 6. Sensor 6 acts by measuring the reflectance or transmission of (E)UV radiation by the optical component to be cleaned. As is depicted in Figure 2, the optical component may be reflective, and the sensor will therefore measure the reflectance of the (E)UV radiation. However, if the optical component is of a transmissive type, the sensor will be positioned such that it measures the degree of transmission through the optical component.

[0049] The degree of absorption of (E)UV radiation can be used to indicate the degree of coverage of the optical component with contaminants. In this embodiment, the system will generally be purged of all (E)UV absorbing agents except molecular oxygen, whose concentration is known and is preferably kept constant. Therefore, any (E)UV absorption observed, aside from that which can be attributed to oxygen present, is due to the presence of

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contaminants. The sensor can, in this way, be used to monitor the level of contamination, and any changes to the level of contamination, of the optical system.

[0050] The sensor may be employed before and/or after cleaning to indicate whether the optical component in question is sufficiently clean for exposure to take place, or whether further cleaning is required. Regular use of this detection process may be desirable so that it can be determined when an optical component requires cleaning. The sensor may also be used during the cleaning process. Cleaning is carried out as described above, and while irradiation is taking place, the absorption of said radiation is monitored using sensor 6. When the sensor indicates that the absorption level has dropped below a sufficient level, and thus the contamination level of the optical component is acceptable, the cleaning process may be stopped.

[0051] Figure 3 depicts a third embodiment of the invention, which is the same as the second embodiment except as described below. In this embodiment a further source of UV or EUV radiation 7 is provided. Source 7 provides radiation having a wavelength of 250nm or less. Suitable sources of such radiation are the same as those described above with reference to source LA.

[0052] In this embodiment, the optical component 3 is irradiated by either EUV or UV radiation having wavelengths shorter than 250 nm, while simultaneously projecting the patterned beam of EUV radiation. Preferably, UV radiation is used, which is capable of selectively dissociating molecular oxygen more profoundly than EUV radiation. For example in the case of oxygen, UV radiation having wavelength of about 157 nm is preferably used. In this way, relatively low concentrations of oxygen in the purge gas can be employed to ensure relatively low absorption of EUV radiation by the cleaning agent. Consequently, the optical component 3 can be cleaned, while exposing a wafer, with acceptable transmission loss.

[0053] It is further contemplated to irradiate the optical component 3 located in space 2 using the UV or EUV radiation supplied from source 7, either before or after exposure by the projection beam PB. Preferably, irradiation is carried out before exposure, thus providing a cleaned optical component which will improve the transmission and uniformity levels during exposure. In this embodiment, the radiation provided by source 7 is depicted as being directed at optical component 3. However, it is also possible to direct the radiation other than directly at the optical component, for example across the optical component.

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[0054] If desired, sensor 6 may be used to monitor the level of contamination as described above.

[0055] In the embodiments described above, a mask or reticle is described, which may also comprise a pellicle. In a space between the mask and the pellicle, a purge gas comprising molecular oxygen can be supplied in order to remove contaminants from said space according to the above-described cleaning process.

[0056] While we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention.

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